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FACTSHEET
ISSN 1198-712X ©Queen's Printer for Ontario
Agdex#: 771 Publication Date: 06/00
Order#: 00-059 Last Reviewed:

Title: Tractor-Driven Generators: Producing Quality Power

Division: Agriculture and Rural
History: Original Factsheet
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Introduction

The prolonged power outage in Eastern Ontario during the 1998 Ice Storm necessitated the continuous use of tractor-driven generators for extended periods of time. Concerns were raised following this event related to a higher than normal number of failures of electrical motors and electronic equipment. An on-farm investigation was conducted to study the operation and power quality of tractor-driven or power-take-off (PTO) driven generators.

This Factsheet will help farmers in the operation of their tractor-driven generators to maximize the quality of power produced. These comments and recommendations are not intended to replace specific details of setup and operation supplied by manufactures, distributors, and electrical contractors.

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Defining Power Quality

Dugan, McGranaghan, & Beaty in their book *Electrical Power Systems Quality* define power quality as:

> *Any power problem manifested in voltage, current or frequency deviations that results in failure or misoperation of customer equipment.*

They explain that the manufacturers of load (electrical) equipment may define

quality power as those characteristics of the power supply that enable the equipment to work properly. These can be very different for different equipment and different manufacturers. Ultimately customers or users of this equipment will see power quality from their own point of view when a piece of equipment fails or malfunctions. What is a problem of power quality for one may or may not be an issue for another based on equipment quality, use, maintenance, and user tolerance.

Much of the published literature related to power quality suggests that 75%-90% of power quality problems are in fact related to wiring issues within the user's facility, with specific reference to grounding and bonding. If you have power quality concerns, consult your electrical contractors and have all electrical wiring and grounds inspected before operating a PTO-driven generator.

Most electrical power used on farms in Ontario is delivered as single phase, alternating current (AC) at 240 volts (V), and 60 cycles per second (60 Hertz or Hz). Quality power then begins with insuring that tractor-driven generators produce electrical power with the same (or similar) consistent characteristics.

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Producing Quality Power

Eighty-four tractor-driven generators were tested (Figure 1) using a portable load cell designed to simulate typical farm electrical power loads.

Figure 1. Generator test set up.

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Voltage Levels

Ontario Hydro (now Ontario Power Generation) has established recommended voltage variation limits for 240 V, single-phase power applicable at service entrance points for rural customers. Voltage levels:

- between 220-250 V are considered "normal",
- between 212-220 V, and 250-254 V are "acceptable for short periods of time", and
- below 212 V or above 254 Vare considered "unacceptable".

Electric motor manufacturers use a standard of 230 V ± 10% (at installation point) as their operational standard. Check with the manufacturer of your electrical equipment for the specific operating ranges required in your operation.

Voltage levels measured during testing were plotted *(Chart 1)* to correspond with Ontario Hydro operating range guidelines. At full load (80%-100% of capacity) the majority of voltage levels (69%) were within their "favourable operating range". An additional 10% were within the "extreme level" range and 21% were above 254 V or unacceptable.

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Chart 1. Distribution of Generator Voltage

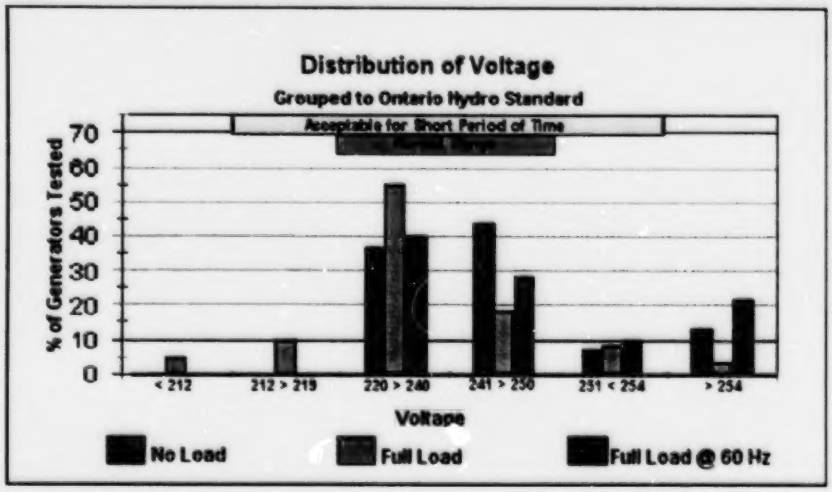

Chart 1 also shows that the speed of the generator (measured as frequency) can have an affect on the voltage output.

Manufacturers are responsible for designing generators to deliver the required voltage at a specified frequency. Operators are responsible for maintaining the required frequency to generate the correct voltage.

Monitor voltage levels:

- during use,
- at periodic service intervals.

Voltage regulation should be adjusted by generator suppliers or service outlets to insure voltage remains within the acceptable operating range.

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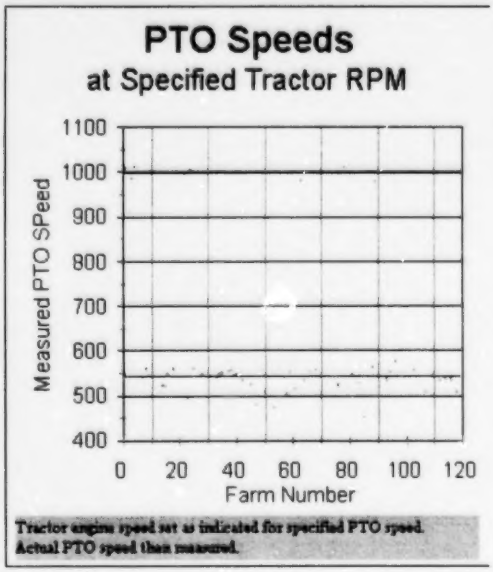
Frequency

The frequency delivered by tractor-driven generators is directly related to the PTO speed of the tractor. This linear relationship is referenced at 540 or 1000 rpm (depending on the generator design), producing an alternating current of 60 Hz. A 10% change in engine speed will cause a 10% change in the PTO speed and a corresponding 10% change in frequency.

Most tractor instrument panels include a tachometer to indicate the engine speed required to deliver 540 (or 1000) PTO rpm. As *Chart 3* shows, these tachometers were extremely inaccurate. For the requested speed of 540 rpm, actual speeds ranged from 450 rpm (-17%) to 600 rpm (+11%). These extremes, if unadjusted while operating the generator, would result in frequency variations from a low of 50 Hz to a high of 67 Hz. A small number of 1000 rpm PTOs were tested and are also shown in *Chart 3*.

While no definitive frequency range standards are available, common industry practice is to accept a frequency range of 60 ± 2 Hz. (58-62 Hz). This amounts to less than a 5% change in frequency and PTO speed.

Chart 2. Actual PTO speeds when set for 540 or 1000 rpm



Tractor engine speed set as indicated for specified PTO speed. Actual PTO speed then measured.

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In addition to the need for specific frequencies for correct electrical equipment operation, ***frequency measurements are the most accurate method of monitoring the PTO input speed.*** The speed of the generator is an important element in delivering the proper voltage level.

Variations in voltage and/or frequency are dependent on a number of factors, including:

- tractor horsepower to generator capacity ratio
- tractor governor design
- age and/or condition of tractor and generator
- loading and unloading patterns
- make of generator
- accuracy of meters
- skill of the operator.

A number of issues *(Table 1)* were identified, during the on farm testing, related to the setup and operation of tractor-driven generators. This Factsheet addresses these issues to help you effectively and efficiently produce the best possible power quality.

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Table 1. Issues identified during testing

Issue	% of Tests
No generator operator's manual	31.0
Tractor tachometer not working	7.1
Tractor tachometer not accurate	*Figure 3*
Tractor throttle issues	7.1
PTO hook-up issues	8.3
Generator running locations	7.1
No generator voltage meter	9.5
Generator voltage meter no working	6.0
Generator voltage meter variation > 10%	3.6
Generator frequency indicator - lights	7.1
Generator frequency indicator - meter	4..8
Owned a hand-held meter	

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Operators Manual

Tractor-driven generators are sophisticated pieces of equipment, designed and manufactured to deliver specified outputs when properly operated and maintained. Just as with all farm implements, the operator's or owner's manual is a critical part of efficient, effective and safe operation. Most generator manufactures can supply replacement manuals and would be a valuable investment. A number of generic operating guidelines have been revised or produced since the ice storm and this information can supply needed direction where no manual is available. OMAFRA Factsheet *Standby Electrical Generators for Emergency Farm Use*, Order No. 99-005 is one example.

Choosing a Tractor

At least 2 tractor horsepower (hp) is required for each kilowatt (Kw) of generator output. While over sizing the tractor may result in a small increase in the amount of fuel used, the extra horsepower and torque will improve conditions for stability of voltage and frequency.

The 2:1 ratio of horsepower to kilowatts is only half the story. Engine torque characteristics and age and/or condition of the tractor are also critical issues in maintaining frequency (speed) as loads change.
Diesel engines used for farm tractor operations have variable speed governors designed to control engine speed at any speed selected by the operator, between low idle and high idle. The disadvantage of this type of governor for generator operation is the change in engine speed that follows any change in load.
Engines used specifically for genset operation are designed with a constant speed governor that will maintain a constant engine speed even with changes in load.

Tractors with a "high torque rise" will generally perform better than those with a relatively flat torque curve. Electronically-controlled engines are now available, allowing the operator to choose the governor characteristics required for a specific

application. Farm equipment dealers can supply specific torque curves for their tractors.

Hours of use, the amount and quality of maintenance and repair can also affect the tractor's ability to maintain engine rpm and the resulting frequency within an acceptable range.

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Chart 3. Significant variation in frequency.

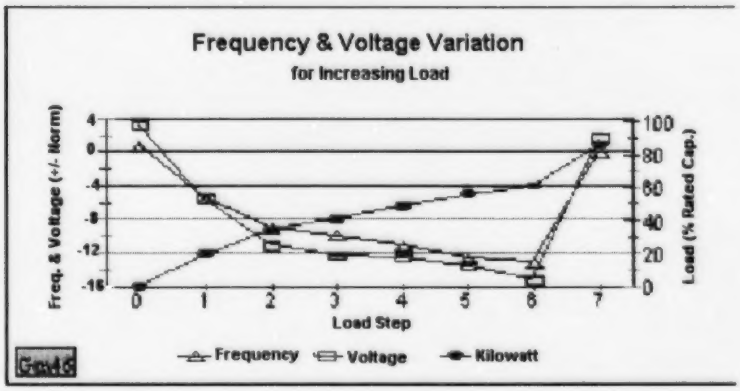

Chart 3 is an extreme example of an older model tractor, meeting the 2:1 hp/kw ratio, but with a large number of hours of use, and a flat torque curve. With only 60% of the rated generated load applied, the frequency had fallen 13% from normal of 60 Hz (to 52 Hz).

In deciding what tractor to use on a PTO driven generator choose one:

- large enough
- in good running condition
- with good resistance to changes in speed as electrical loads are applied and removed.

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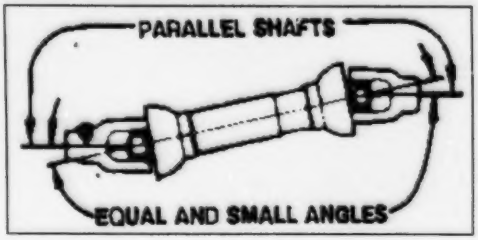
Generator/Tractor Hookup

Power-take-off alignment, generator mounting, and operating location are all issues having an impact on power quality and safety.

The recommendations for proper PTO shaft use are the same as for all PTO driven equipment.

- Use only the PTO shaft purchased with your generator. It must be straight, the right length and strong enough to transmit the required horsepower.
- With the tractor and generator in running position the tractor shaft and gearbox shaft should be parallel (side and top view). Keep joint angles equal *(Figure 2)* and as small as possible (maximum 10 degrees).
- Keep PTO shields in place and in good repair.

Figure 2. PTO shaft alignment.



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Generators are typically mounted on a 2-wheeled trailer, for portability, or on a permanent concrete slab. The mounting method must be stable enough to prevent the generator from tipping over or lifting on one side as loads are applied. In choosing your mounting method:

- Use a trailer wide enough with an axle strong enough to prevent flipping under load.
- Use rubber bushings when mounting a generator on a concrete pad.
- Insure the correct alignment of the PTO shaft
- Operate with PTO shaft as short as possible.

In selecting an operating location, personal safety and long generator life are the major concerns. The generation of electricity produces large amounts of heat. In selecting a operating location:

- Operate in a dry location with shelter from direct and/or driving rain or snow.
- Provide sufficient ventilation to prevent over heating of generator. (500 cm^2 or 0.5 ft^2 of inlet and outlet air opening for each 1 Kw of generator capacity)
- Direct exhaust from tractor to the outdoors if tractor is running inside a building.
- Follow the directions of your electrical contractor in properly grounding the generator and electrical service.

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Tractor Operation

After choosing the tractor best suited for operating a generator there are a number of issues to address to insure proper generator operation:

- Tachometer must be working and calibrated with a hand-held tachometer or by a tractor dealer.
- Tractors with digital read-outs for engine and PTO speed give a more accurate indication of speeds while using the engine read-out. Most readings are in multiples of "tens" and 10 PTO rpm will cover 40 engine rpm. Know the engine rpm required to deliver 540 (or 1000) PTO rpm and set to that reading.
- Throttles must be free enough to make fine adjustments, but firm enough to hold for hours of unattended operation.
- High-idle settings need to be set to correct value (to maintain proper speed at full loads). This is an adjustment your tractor equipment dealer would check and set.
- Throttle and governor linkage should be checked for wear. Excessive wear can effect high-idle settings and governor response to load changes.
- Turn off the cab air conditioning when operating a generator. The cycling of the compressor can cause frequency changes in excess of ± 1%
- Check tractor for oil and/or coolant leaks or other potential problems. Unattended, long term operation of a tractor on a generator will not cause any harm to the tractor as long as nothing breaks or leaks.

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Figure 3. Example of PTO running at severe angle.

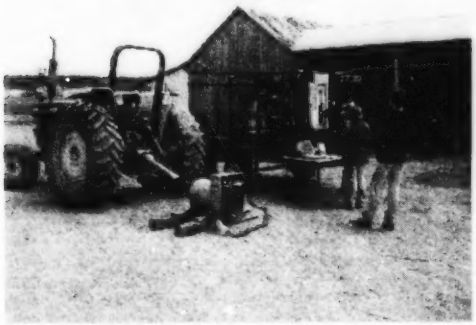

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Figure 4. A simple roof to protect generator from rain and snow.

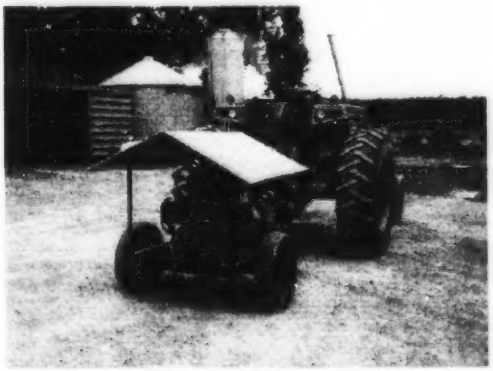

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Figure 5. Example of a shelter too small for personal access and has no ventilation.

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Figure 6. Large building allows access to generator. Cross ventilation keeps it cool.

Generator is mounted on a concrete pedestal at the level required to allow PTO shaft to run straight.

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Generator Condition

Generators need to be properly maintained if they are to perform reliably. Inspect the generator before each use looking for:

- loose or broken wires
- defective connections
- missing, corroded or damaged fasteners and other hardware
- low oil levels and/or oil leaks in gearbox
- general appearance and cleanliness.

Generators should be operated under load at least a couple of times a year.

Periodic inspection and service should be performed by a qualified generator servicing business; checking for:

- condition and operation of brushes
- defective internal wires, connections and other components,
- effectiveness and adjustment of voltage regulation
- accuracy of meters.

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Voltage Regulation

The response and effectiveness of the voltage regulation built into each generator is dependent on the design criteria used by each manufacturer. Two measures of voltage regulation are of interest when buying and/or using a tractor-driven generator.

1. What is the change in voltage as the electrical demand on the generator goes from no load to full load at a constant frequency of 60 Hz?
2. What is the change in voltage as the frequency (speed) changes because of varying electrical loads?

Chart 4 is an example of voltage regulation remaining reasonably constant as the frequency is reduced by more than 6%. This generator is able to supply a constant voltage over a broad range of loads and frequencies. Tractor speed variations, because of changes in electrical load, have minimal effect on the voltage output.

Chart 5, on the other hand, is an example of voltage fluctuating as load is applied to

the generator. Even returning the frequency to 60 Hz does not return the voltage to the no-load value. The voltage output of this generator is affected both by changes in load and changes in speed. Voltage output from a generator with voltage regulation represented by this figure would need to be monitored more closely than the one represented in *Chart 4*.

There are limits to the ability of voltage regulation to deal with changes in frequency (speed). *Chart 6* is an example of voltage regulation maintaining a constant voltage until the frequency (speed) decreases by more than 5%. At that point voltage decreases very quickly. All generators will reach a point at which the voltage regulation is no longer able to maintain an acceptable voltage. The closer frequency is kept to 60 Hz, the less opportunity there is for out of range voltage levels.

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When purchasing a PTO-driven generator or arranging an inspection on an existing unit:

- ask for voltage levels at "no-load" and "full-load" at 60 Hz
- ask for an explanation of voltage output variations when PTO speed (frequency) varies from +5 to -5 %, at a variety of load levels.

While operating a PTO-driven generator:

- monitor the voltage and the frequency of the power output
- adjust tractor speed to maintain frequency between 60 and 62 Hz
- in the absence of a frequency meter adjust the tractor speed to maintain 540 (or 1000) PTO rpm
- contact your generator supplier if the voltage is outside of acceptable levels
- get to "know" your generator and tractor in order to know when something is not right.

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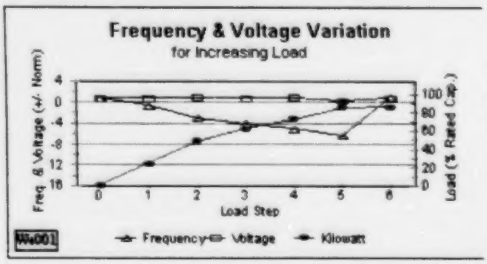

Chart 4. Voltage drops as load increases and speed slows.

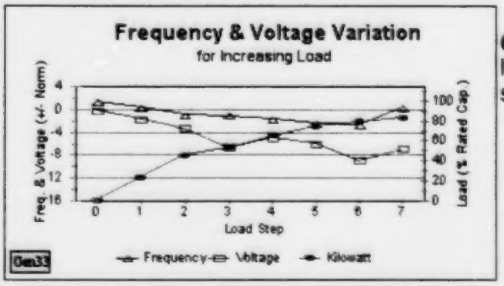

Chart 5. Voltage drops as load increases and speed slows.

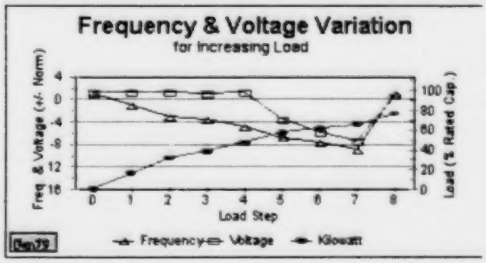

Chart 6. Breakdown of voltage regulation as frequency dropped.

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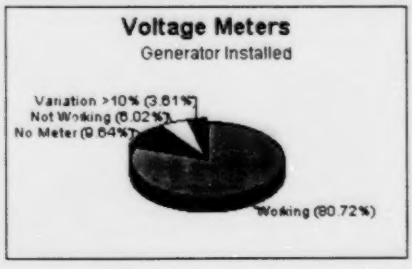
Monitoring Generator Output

While the majority of generators sold in Ontario have some method of monitoring voltage, 20% of the units tested had no effective method of monitoring voltage output *(Chart 7)*. Very few had any method of checking the frequency *(Table 1)*.

Chart 7. Twenty percent of generators had no effective voltage gauge.



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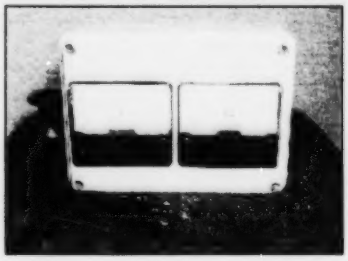
The most important step an operator can take in improving power quality is to use an independent, good quality voltage and frequency meter to monitor generator power output. A number of types and styles are available in the $200 to $400 range.

Meters that can be plugged into any 120 V receptacle are available with either

analog *(Figure 7)* or digital read-outs. Hand-held multi-meters are also available, with and without the ability to measure current as well. When purchasing a hand held unit, insure it will measure frequency at 60 Hz.

Figure 7. Voltage/Frequency Meter



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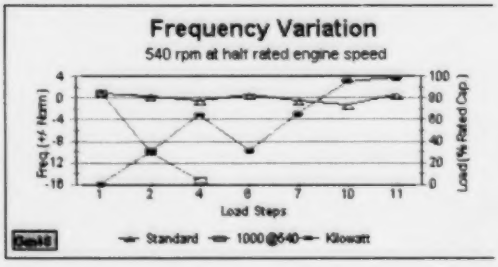
Operating at Half Engine Speed

Farm tractor diesel engines are designed to develop optimum horsepower and torque at a specific rated engine speed.

Operating a tractor with a 1000 rpm PTO at approximately one-half its rated engine rpm to deliver 540 rpm to the generator is not a recommended practice.

Chart 8 shows the results of one test where this mode of operation was attempted. The frequency decreased by 10% when 30 % of rated load was applied and by 16% at 60 % of rated load. Clearly unacceptable, for producing quality power.

Chart 8. Significant change in frequency takes place when operating at half of rated engine rpm.



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While the engine horsepower would be significantly reduced at half the rated engine rpm, the bigger problem is that at this speed the engine is operating on the unstable side of the torque curve. An increase in load will cause a reduction in engine speed, which causes a reduction in torque, which causes a reduction in speed, resulting in tractor stalling or speed cycling erratically up and down.

Some tractors are now equipped with an "economy" 540 rpm PTO as well as the "standard" setting. One tractor with this feature was tested. Operating with the "standard" setting produced a 2% drop in frequency from no-load to full-load operation. The frequency drop while operating in the "economy" setting was in excess of 6% for the same loads.

When selecting the engine operating speed to deliver 540 rpm at the PTO:

- set the engine close to manufactures recommended engine speed for 540 rpm
- adjust frequency to 60-62 Hz
- use a factory "economy" setting for light consistent loads
- do not operate your tractor with 1000 rpm PTO and half engine speed.

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The information in this Factsheet has been complied from data and observation collected during on-farm testing and in consultation with the generator industry. It is not intended as a substitute for the professional advice from manufacturers or certified suppliers of tractor-driven generators. Consult your electrical contractor for assistance in following Electrical Safety Code requirements.|

Funding for this project has been provided under the Canada-Ontario agreement for the Ice Storm Recovery Assistance Program, Annex A, Assistance for the Agricultural Sector and Rural Communities in Eastern Ontario. This program is jointly funded by the Government of Canada and Government of Ontario.

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The authors wish to thank the following people for their technical assistance with this Factsheet: Charlene Renkema, Kristina Shwaykowski and Leah Ann Vibert, all with Kemptville College, University of Guelph.

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